For components made from quenched and tempered steels, it shall be essential, that a totally new quenching and tempering operation is performed on the whole component after hot forming. For the hot forming itself, the procedures described in 7.3.9.1a) shall apply.

NOTE **Austenitic steels**. The forming requirements applicable to austenitic steel plates are the subject of development. In the meantime, the methods used in accordance with the manufacturer's own proven procedures ensure that, by their use, the safety of the boiler is not impaired.

10.2.2 Heat treatment associated with forming

The heat treatment required by this document, after hot or cold forming, depends on the requirements of the base material specification or data sheet, and normally be one of the following processes:

- normalizing;
- normalizing plus tempering;

NOTE Tempering can be part of the stress relieving process of welds, if applicable.

- quenching plus tempering;
- solution annealing.

Other heat treatment(s) may be applied, if they are in accordance with a qualified procedure, and the product shall be tested after forming to demonstrate the adequacy of the material property values in the finished component.

10.2.3 Shells and strakes

Where a plate is bent to a mean radius less than ten times the plate thickness, it shall be heat treated after bending to the requirements of 10.2.2. However, in the case of materials for which normalizing or normalizing and tempering are the final heat treatments specified in the material specification, or data sheet, the following shall apply:

a) when the final heat treatment specified is normalizing, provided the component has been heated uniformly to the normalizing temperature during forming, no further heat treatment is required;

b) when the final heat treatment specified is normalizing and tempering, provided the component has been heat treated uniformly to the normalizing temperature during forming, only additional tempering is required.

10.2.4 Ends

All ends made from plate shall be heat treated after forming to the requirements of 10.2.2. However, in the case of materials for which normalizing or normalizing and tempering are the final heat treatments specified in the material specification, or data sheet, the following shall apply:

a) when the final heat treatment specified is normalizing, provided the component has been heated uniformly to the normalizing temperature during forming, no further heat treatment is required;

b) when the final heat treatment specified is normalizing and tempering, provided the component has been heat treated uniformly to the normalizing temperature during forming, only additional tempering is required.

10.2.5 Production test requirements for formed components

Production test coupons shall be provided for hot formed shells, strakes and ends. The number of test coupons required shall be as follows:

a) **shells and strakes** – one test coupon per drum. This may, at the manufacturer's risk, be produced as an extension of the weld production test plate, provided that the test plate has been made from the same material as that supplied for the shells or strakes and which has been heat treated with one of the shells or strakes;

b) **ends** – one test coupon per heat treatment batch.

The coupons shall be tested to replicate the mechanical tests carried out on the base material by the material supplier.

In the event of a failure of any of the production tests, further testing shall be permitted. This shall be in accordance with the re-testing procedures given in the material specification or data sheet.

10.3 Pre-heating for welding and thermal cutting

10.3.1 General

To avoid hard zone cracking in the heat-affected zones of welds and thermally-cut surfaces, consideration shall be given, where appropriate, to the application of pre-heating prior to the commencement of welding, including tack welding, and thermal cutting.

No welding or thermal cutting operations shall be carried out on boiler components when the temperature of the component in the welding or cutting zone is below 5 °C.

NOTE When necessary, staging and protection from the weather is important in order to ensure the welding or thermal cutting operations can be performed under satisfactory working conditions.

10.3.2 Pre-heating for welding

10.3.2.1 The manufacturer shall include in the welding procedure specification the pre-heating temperatures and, where relevant, the inter-pass temperatures required for the welding. The pre-heat temperature shall be determined by taking into consideration the welding process, the composition and thickness of the metal being welded, the type of joint, the consumable being used and the heat input involved. General recommendations for pre-heating are contained in EN 1011-1:2009.

10.3.2.2 Where the welding process employed for the root runs differs from that used for subsequent runs, the pre-heating, if any, applicable to each process, shall be determined separately. Any change in pre-heating temperature required, shall be made after the completion of welding by the first process, but before the next process is commenced.

10.3.2.3 Where the risk of hydrogen cracking exist, e.g. under conditions of severe restraint, consideration shall be given to the benefits of either maintaining or boosting the pre-heat temperature for a minimum of two hours after the welding has been completed, or applying an intermediate post-weld heat treatment to facilitate hydrogen removal.

10.3.2.4 Where pre-heating is specified, welding, where practicable, shall be continued without interruption. If the continuity of the pre-heating is interrupted, the welding shall be discontinued and the joint shall be allowed to cool slowly by wrapping in a dry insulating blanket. The preheat shall be re-applied before further welding is commenced.

10.3.2.5 Austenitic steels do not require pre-heat for welding.

10.3.2.6 No welding or tack welding shall be carried out when the temperature of the parent metal within 150 mm of the joint is less than 5 °C.

10.3.3 Pre-heating for thermal cutting

Pre-heating temperatures for thermal cutting shall be determined by the manufacturer. Recommendations are given in Table 10.

Table 10 — Recommended preheat temperatures for thermal cutting

Steel type	Steel group	Thickness mm	Minimum preheat temperature °C
C	1.1	≤ 150	Not required
C-Mn		> 150	50
0,3Mo	1.1	< 30	Not required
		≥ 30	100
20MnMoNi	2.2	< 15	Not required
		≥ 15	150
15MnCrMoNiV	4.1	< 15	Not required
15NiCuMoNb	4.2	≥ 15	150
1 Cr-1/2Mo	5.1	< 50	Not required
		≥ 50	150
2 1/4Cr-1Mo	5.2	< 50	100
		≥ 50	150
Cr-Mo-V	6.2	< 50	100
		≥ 50	150
9Cr-1Mo	6.4	All	150
9Cr-2Mo			
12Cr-1Mo-V	6.4	All	200
The above recommendations should be considered as a general guide to good practice. Other pre-heating temperatures are permitted.			

10.3.4 Measurement of pre-heat

10.3.4.1 The manufacturer shall implement procedures for the measurement and maintenance of the pre-heat temperature. Guidance is given in EN ISO 13916:2017.

NOTE Acceptable methods of temperature measurement include temperature-indicating crayons and/or thermo-couples.

10.3.4.2 The pre-heat temperature shall be checked periodically during the period of application.

10.4 Post weld heat treatment

10.4.1 General

10.4.1.1 The methods of post-weld heat treatment are given in 10.4.2 and post-weld heat treatment procedures are given in 10.4.3. Where, for practical reasons, it is necessary to adopt different methods or procedures, they shall be permitted when:

- the proposed methods or procedures are based on simulation tests on specimens of the material; or
- the methods or procedures are proven by other means as representing safe practice.

The manufacturer shall fulfil the quality requirements for post weld heat treatment according to EN ISO 17663:2009 as appropriate.

10.4.1.2 The equipment for heat treatment shall be suitable for the heat treatment in question. It shall enable the temperature within the component to be controlled with adequate accuracy and uniformity, especially for those materials which have a small permissible heat treatment temperature range.

10.4.1.3 Heat treatment records shall be provided which indicate the temperature, the method and rate of heating and cooling, and the holding time. Records shall also be available showing the temperature of martensitic transformation for materials of steel group 6.

10.4.1.4 Except in the cases covered by 8.9 and 9.4.1, post-weld heat treatment shall be carried out after all welding has been completed.

In selecting the temperature to be used for heat treatment, the criteria given in Table 11 should be adopted.

Table 11 — Criteria for selecting the temperature

Method	Control temperature
Furnace heat treatment	Use the middle of the specified range.
Non-furnace heat treatment (resistance, induction, controlled flame, etc.)	Use the upper end of the specified range.
Additional heat treatment (intermediate or repair)	Use the lower end of the specified range.

10.4.1.5 The temperature ranges and holding times used for post-weld heat treatment shall be to the ranges given in Table 12 and Table 13.

Table 12 — Temperature ranges for post-weld heat treatment for welded joints of similar and dissimilar materials

Steel type	Steel group	Temperature range °C								
		1.1–1.4	1.1	2.2 + 4.1 + 4.2	5.1[d]	6.1	5.2[e]	6.2[c]	6.4[a]	6.4[a]
C-Mn	1.1–1.4	550 to 600	550 to 600	550 to 600						
0,3Mo	1.1		550 to 630	550 to 600	600 to 630					
20MnMoNi 15MnCrMoNiV 15NiCuMoNb	2.2 4.1 4.2[f]			570 to 620	600 to 620					
1Cr1/2Mo[d]	5.1[d]				620 to 700	650 to 700	650 to 700			
14MoV	6.1					680 to 730	690 to 730			
2 1/4Cr1Mo[e]	5.2[e]						680 to 730	730 to 750	730 to 760 710 to 730[b]	
Cr-Mo-V[c]	6.2[c]							720 to 760	740 to 760	740 to 760
9Cr1Mo 9Cr2Mo	6.4[a]								740 to 780	740 to 770
12Cr1Mo-V	6.4[a]									730 to 770

Other material combinations not covered by the table above, and variations from the temperatures given in the table above, may be acceptable, provided the manufacturer can ensure that, by their use, the safety of the boiler is not impaired.

The temperature for PWHT of dissimilar joints between austenitic and ferritic materials should be required for the ferritic side of the joint.

[a] These materials require transformation to martensite prior to post-weld heat treatment (PWHT).
[b] Only for filler of the type 2 1/4Cr1Mo.
[c] No PWHT required if the joint is welded with similar filler using TIG process and minimum specified weld thickness $e \leq 10$ mm.
[d] No PWHT required on welds (W1-W6) if all the following conditions are fulfilled: $d_o \leq 114{,}3$ mm and $e \leq 7{,}1$ mm. An exception to this is the membrane tube walls with e ≤ 13 mm.
[e] No PWHT required on welds (W1-W6) if all the following conditions are fulfilled: calculation temperature > 480 °C; nominal diameter $d_o \leq 114{,}3$ mm and minimum specified weld thickness $e \leq 7{,}1$ mm. An exception to this is the membrane tube walls with e ≤ 13 mm.
[f] Quenched and tempered steels should be given a PWHT at a temperature not exceeding 20 °C lower than the tempering temperature.

Table 13 — Holding time for post-weld heat treatment conditions for welded joints

Typical steel type	Steel group	Zone I		Zone II		Zone III	
		Min. specified weld thickness e mm	Min. holding time t_1 min	Min. specified weld thickness e mm	Min. holding time t_2 min	Min. specified weld thickness e mm	Min. holding time t_3 min
C-Mn	1.1 – 1.4	$e \leq 35$	PWHT n.r.	$35 < e \leq 90$	$t_2 = 1 \times e$	$e > 90$	$t_3 = 90 + 0{,}5 \times (e - 90)$
0,3Mo	1.1	$e \leq 35$	PWHT n.r.	$35 < e \leq 90$	$t_2 = 1 \times e$	$e > 90$	$t_3 = 90 + 1 \times (e - 90)$
20MnMoNi 15MnCrMoNiV 15NiCuMoNb	2.2 4.1 4.2	$e \leq 13$	$t_1 = 15$	$13 < e \leq 60$	$t_2 = 1 \times e$, min. 15	$e > 60$	$t_3 = 60 + 0{,}5 \times (e - 60)$
$1Cr^{1/2}Mo$	5.1	$e \leq 13$	$t_1 = 30$	$13 < e \leq 60$	$t_2 = 2 \times e$, min. 30	$e > 60$	$t_3 = 120 + 1 \times (e - 60)$
14MoV	6.1	$e \leq 15$	$t_1 = 15$	$15 < e \leq 60$	$t_2 = 1 \times e$, min. 15	$e > 60$	$t_3 = 60 + 0{,}5 \times (e - 60)$
$2\ ^{1/4}Cr1Mo$	5.2	$e \leq 13$	$t_1 = 30$	$13 < e \leq 60$	$t_2 = 2 \times e$, min. 30	$e > 60$	$t_3 = 120 + 1 \times (e - 60)$
Cr-Mo-V	6.2	$e \leq 13$	$t_1 = 30$	$13 < e \leq 60$	$t_2 = 2 \times e$, min. 30	$e > 60$	$t_3 = 120 + 1 \times (e - 60)$
9Cr1Mo 9Cr2Mo	6.4	$e \leq 13$	$t_1 = 30$	$13 < e \leq 90$	$t_2 = 2{,}5 \times e$	$e > 90$	$t_3 = 225 + 1 \times (e - 90)$
12Cr1MoV	6.4	$e \leq 13$	$t_1 = 30$	$13 < e \leq 90$	$t_2 = 2{,}5 \times e$	$e > 90$	$t_3 = 225 + 0{,}5 \times (e - 90)$

Typical steel type	Steel group	Zone I		Zone II		Zone III	
		Min. specified weld thickness	Min. holding time	Min. specified weld thickness	Min. holding time	Min. specified weld thickness	Min. holding time
		e	t_1	e	t_2	e	t_3
		mm	min	mm	min	mm	min

The holding times to be used for joints of dissimilar materials should be in accordance with the manufacturer's own proven procedure which shall ensure that, by their use, the safety of the boiler is not impaired.

NOTE 1 See Figure 8 for example of applying this table.

Key

t minimum holding time

e minimum controlling weld thickness

[a] see column 4

[b] $t_2 = (1...2,5) \times e$ (see column 6)

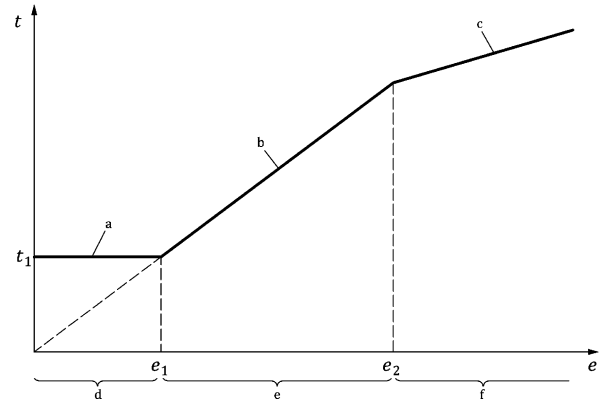
[c] $t_3 = t_2 + (0,5...1)\ (e - e_2)$ see column 8

[d] Zone I

[e] Zone II

[f] Zone III

n.r. = not required



NOTE 2 Read in conjunction with Table 13.

NOTE 3 The controlling weld thickness is given in 10.4.1.6 and 10.4.1.7.

Figure 8 — Examples of applying minimum holding times for different controlling weld thicknesses

10.4.1.6 Where the component contains welded joints connecting parts which differ in thickness, the controlling thickness to be used in determining the requirements for post-weld heat treatment times shall be as given in Table 14.

Table 14 — Controlling thickness for different joint types

Joint type	Controlling thickness
Butt welds (W1)	The thickness of the thinner part at the welded joint.
Fillet welds (W2)	The specified throat thickness of the weld.
Set-on branch (W3)	The thickness of the branch at the joint.
Set-in or set-through branch (W4)	The thickness of the shell at the joint.
NOTE See Figure 9 for examples of W1, W2, W3 and W4.	

When the component to be post-weld heat treated contains welds with different individual controlling thicknesses, the governing thickness to be used to determine the overall post-weld heat treatment shall be the greater of the individual controlling thicknesses.

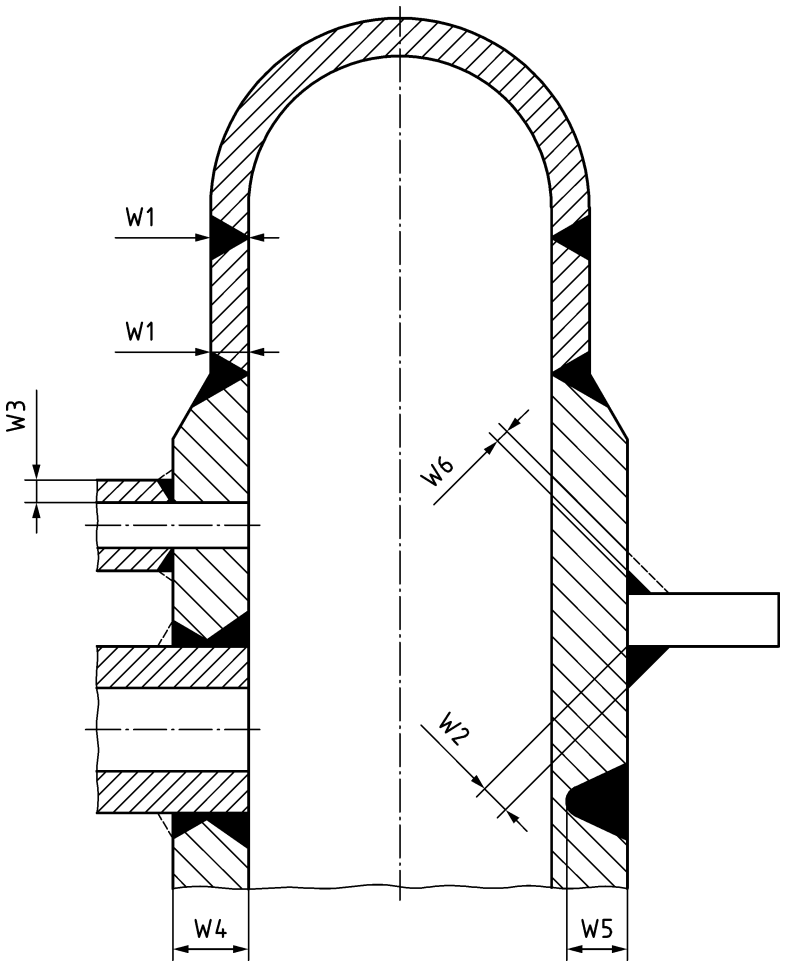
10.4.1.7 When weld repairs or modifications have been made to a component after the final post-weld heat treatment stage, except as in the case covered by 8.9, further heat treatment shall be carried out in accordance with the requirements of 10.4. The controlling thickness to be used in defining the time required at temperature shall be one of the following:

a) the depth of the weld repair (W5);

b) the throat thickness of the weld where additional welds are added for modification purposes, see 10.4.1.6;

c) the thickness of the additional weld runs where reinforcement is added (W6).

See Figure 9 for examples of W5 and W6.



NOTE Dimensional and operation temperature limitations are given in Table 12 and Table 13.

Figure 9 — Typical examples of controlling thicknesses

10.4.1.8 Intermediate heat treatment shall be implemented at the manufacturer's discretion to facilitate fabrication. The duration of such intermediate heat treatment shall be decided by the manufacturer but the temperatures employed shall not exceed those given in Table 12. Temperatures and times of intermediate heat treatment shall be recorded.

10.4.2 Methods of post weld heat treatment

10.4.2.1 Wherever possible, the component should be heat treated as a whole in an enclosed furnace heated by gas or by electricity. Where this is impracticable, it is permissible to adopt the methods described in 10.4.2.2 to 10.4.2.5 (see also Figure 10).

10.4.2.2 It is permissible to heat treat sections of the completed component in an enclosed furnace, provided the overlap of the previously heat treated sections is at least 1 500 mm or $5 \times \sqrt{r_{is} e_s}$, whichever is the greater, where r_{is} is the internal radius of the component and e_s is the nominal thickness at the weld.

Where this method is used, the portion outside the furnace shall be shielded so that the longitudinal temperature gradient is such that the distance between the peak and half-peak temperatures is not less than $2{,}5 \times \sqrt{r_{is} e_s}$.

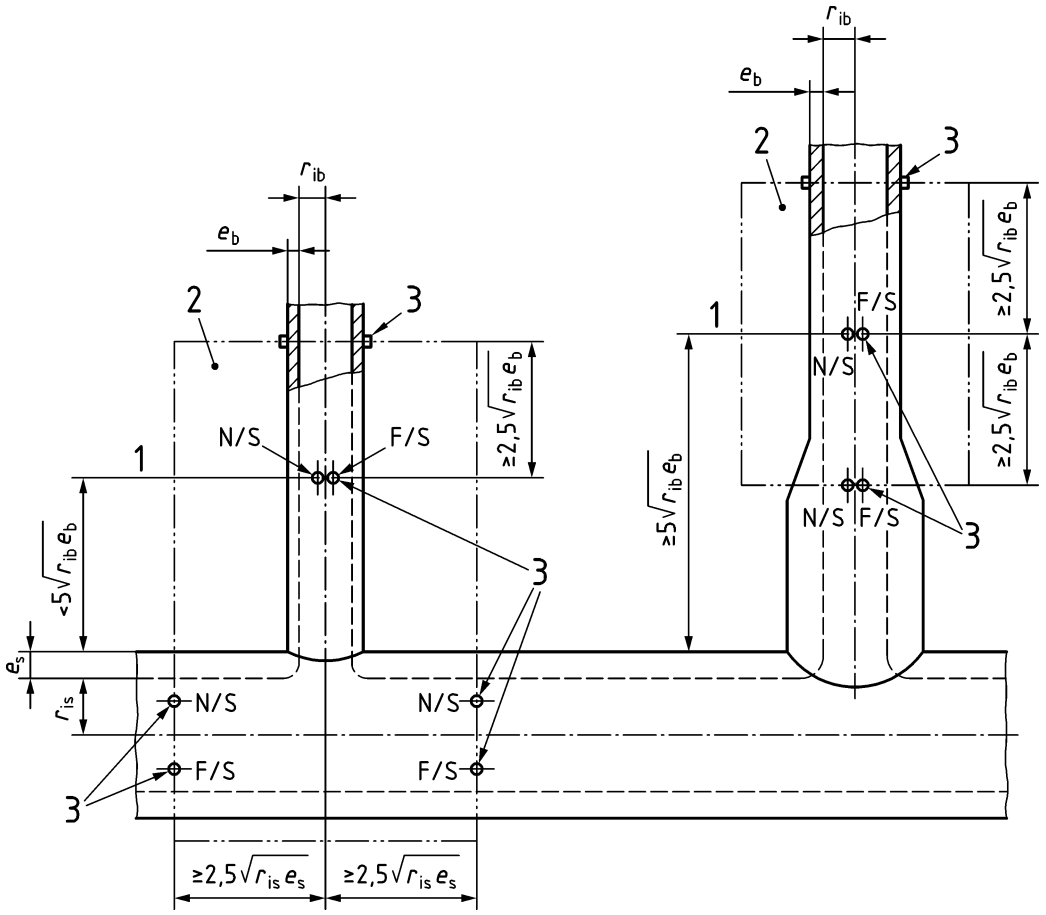
10.4.2.3 It is permissible to locally heat treat circumferential seams by heating an insulated band around the entire circumference of the component. The width of the heated band shall not be less than $5 \times \sqrt{r_{is} e_s}$, the weld being in the centre.

Where the circumferential weld to be heat treated is between component strakes and a dished or hemispherical end, the whole of the end shall be included in the heated band. The heated band width on the component course side shall be at least $2{,}5 \times \sqrt{r_{is} e_s}$.

Sufficient insulation shall be fitted to ensure that the temperature of the weld and its heat affected zones is not less than that specified and that the temperature at a distance of $2{,}5 \times \sqrt{r_{is} e_s}$ from the centre line of the weld is not less than the half-peak temperature. In addition, the adjacent portion of the component outside the heated zone shall be thermally insulated such that the temperature gradient is not harmful.

A minimum total insulated band width of $10 \times \sqrt{r_{is} e_s}$ is recommended for the purpose of complying with this requirement.

10.4.2.4 Where tubes or fittings are subsequently butt welded to branches or stubs on a shell, and post-weld heat treatment is required according to 10.4.1, it is permissible to locally post-weld heat treat the butt welds by heating insulated bands around the component as shown in Figure 10. The disposition of the heating elements and insulation around the butt weld shall be such as to produce a temperature profile which is approximately symmetrical about the weld and circumferentially uniform.



Key

1 site weld

2 heated zone

3 thermocouples

Minimum requirements are one near side (N/S) and one far side (F/S) per position as indicated.

Figure 10 — Minimum heated band widths for local heat treatment

Where the attaching butt weld is at a distance not less than $5 \times \sqrt{r_{ib}e_b}$ from the branch/stub to shell weld it may be post-weld heat treated in isolation (see Figure 10 right side). Where the attaching butt weld is at a distance less than $5 \times \sqrt{r_{ib}e_b}$ from the branch/stub to shell weld the post-weld heat treatment shall be applied simultaneously to the butt weld and the branch/stub to shell weld as shown in Figure 10 at left side.

The temperatures measured at a distance of not less than $2{,}5 \times \sqrt{r_{ib}e_b}$ from the centreline of the butt weld, or $2{,}5 \times \sqrt{r_{is}e_b}$ from the outside surface of the branch/stub axis where appropriate, shall not be less than one-half the specified temperature measured at the butt weld.

Care shall be taken during welding and post-weld heat treatment of the butt weld to ensure harmful temperature gradients do not occur local to the weld between the shell and the branch/stub.